Data and Work Sheets - Staple these sheets together before submitting

Simple Harmonic Motion - Physics 1402B
2021-2022

Please circle the appropriate values											
Course	**1102B**		**1202B**		**1402B**		**1502B**				
Lab Section	**002**	**003**	**004**	**005**	**006**	**007**	**008**	**009**	**010**	**013**	**014**
Lab Subsection	**A**	**B**	**C**	**D**							
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Lab Station #	15										
Date	March 30 2022										
Demonstrator	Sofia and Logan										

Disclaimer: Please note that some but not all questions in this lab writeup will be graded.

EXPERIMENT 1: MEASURING THE SPRING CONSTANT OF THE SPRING

APPARATUS: steel helical spring, masses, meter ruler and mirror (to eliminate parallax)

METHOD

You should have a setup as shown in Figure 1. The spring is hung on a force sensor. The force sensor and the ultrasonic device are not used in Experiment 1 when the spring constant is measured, but will be used in Experiment 2.

Record in Table 1 the position of the lower end of the helical spring with no masses attached. This is the equilibrium position, x_0, of the spring. Now, add a mass to the spring and record the mass (m) attached to the spring, and the position (x) of the lower end of the spring, in Table 1. (Note that you should always start with the lowest mass so as to not elongate the spring past its breaking point. The displacement ($x - x_0$) should be at least 3 cm and **no more than 20 cm**. Continue to increase the load on the spring by small increments, by either adding masses or by substituting a heavier mass, and record the position of the lower end of the spring for each mass. Add masses gently so that the spring extends monotonically, i.e., without bouncing the load on the spring. Repeat this process for at least 4 different masses.

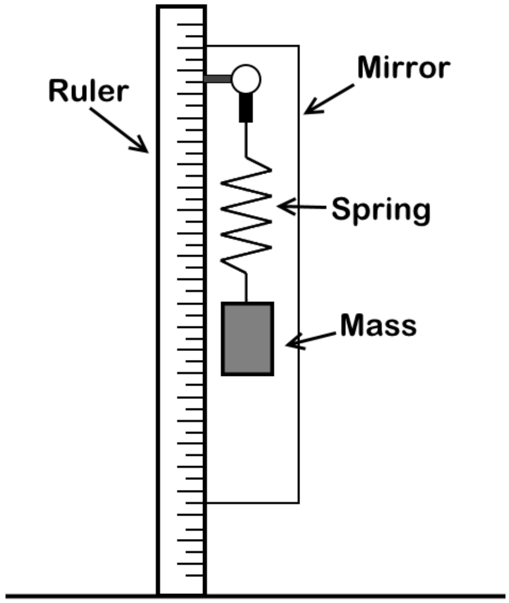

Figure 1: Setup of vertical mass-spring system. The spring is suspended vertically and extended due to the weight of a mass attached to the end. The mirror is used to reduce measurement errors due to parallax. The force and motion sensors are not shown in this schematic.

Calculate the corresponding displacement $(x - x_0)$ of the spring for each mass, and record $(x - x_0)$ in Table 1. The displacement is the increase in length from the equilibrium position of the spring. Include an estimate of uncertainty in the column heading for each variable.

Table 1: Static (non-oscillatory) force-displacement data for determining the spring constant of the mass-spring system

Mass m (g) $\pm$	**Position x (cm)** $\pm$	**Weight (N)** $\pm$	**Displacement $(x - x_0)$ (m)** $\pm$
0.0	25	0.0	0
150	32.1	1.4715	5.1 cm .051 m
200	37.1	1.962	7.1 cm .071 m
250	41.6	2.4525	16.1 cm .161 m
300	46.3	2.943	21.3 cm .213 m

EXPERIMENT 1(a): DETERMINATION OF THE SPRING CONSTANT

1. Using *Excel*, plot weight (in Newtons) versus displacement ($x - x_0$).

2. Fit a straight line without forcing the fitted line through the origin to determine the spring constant k. In *Excel*, use the "Add Trendline" function to add a linear line with the display equation option selected.

3. Determine the slope.

What is the spring constant?

12.117 N/m

EXPERIMENT 2: DETERMINATION OF THE PARAMETERS OF A SIMPLE HARMONIC MOTION

In this experiment, you will record the position, velocity, acceleration and force using the ultrasonic position-measurement device and a force sensor. The parameters of the oscillation will be obtained by graphical analysis of data collected by the *Logger Pro* software on the lab computers.

Each group will measure the oscillation of the vertical mass-spring system using the same spring but with two different masses but the same amplitude. Then they change the amplitude and repeat the experiment for the two different masses chosen. The students will analyze the data each time to investigate the effects of changing the mass as well as changing the amplitude on the motion of the simple harmonic oscillator.

EXPERIMENT 2(a): SETUP

In this experiment, you will now use the Vernier force and position sensors to acquire data from the oscillation of a mass on a spring, as shown in Figure 2.

1. Ensure that both sensors are connected to the mini Lab Quest data hub, and the hub is connected to the computer.

2. Position the ultrasonic sensor **directly** underneath the spring. There needs to be a minimum of 15 cm between the sensor and the mass on the spring for the sensor to record accurately.

3. Select 10 N range for the force sensor.

4. Select "cart" position for the ultrasonic position sensor.

We want to choose a mass such that oscillations will be about an equilibrium position that stretches the spring by approximately 8-12 cm.

1. Start up the *Logger Pro* software, and select the use of both the force and the position sensors.
2. Hang your chosen mass, and let the spring-mass system come to an equilibrium. You may have to wait a minute or so for it to come to rest.
3. Under the menu "Experiment", choose "zero" to zero both the force and the position sensors (see Figure 3).
4. To start collecting data, click on the green arrow button labelled "Collect".
5. The *Logger Pro* is setup to collect 25 measurements per second over a period of 10 seconds.
6. Without any motion, collect a baseline set of data (see Figure 4).
7. The vertical axis range of each graph can be changed. You may click on any number on the vertical axis to change the range.

EXPERIMENT 2(b): WHAT TO MEASURE

1. Each station will accommodate two students who work in pairs using the same spring. You will use two different masses, allowing the spring to stretch by approximately 8-12 cm from the equilibrium each time.
2. You will then setup and record two sets of oscillations using two different amplitudes (e.g., amplitudes between 1-3 cm for the first set and 3-6 cm for the other set). Label and save your data. You will need to use the data for the two sets of amplitudes later in the analysis section.
3. While working together, lab partners will need to take turns using the equipment. Once you finished acquiring data for one mass and one amplitude, save your work on the Desktop, and open it with *Excel* to do the analysis (see the Analysis sections). Be sure to give your file a meaningful name when saving your work so you know which mass and amplitude you used. Then acquire data for the *same* mass using a *different* amplitude. Analyze the data and save your work under a different name. Repeat the above procedure for a different mass and the above two amplitudes. You should acquire 4 sets of data (i.e., two different masses, two different amplitudes).

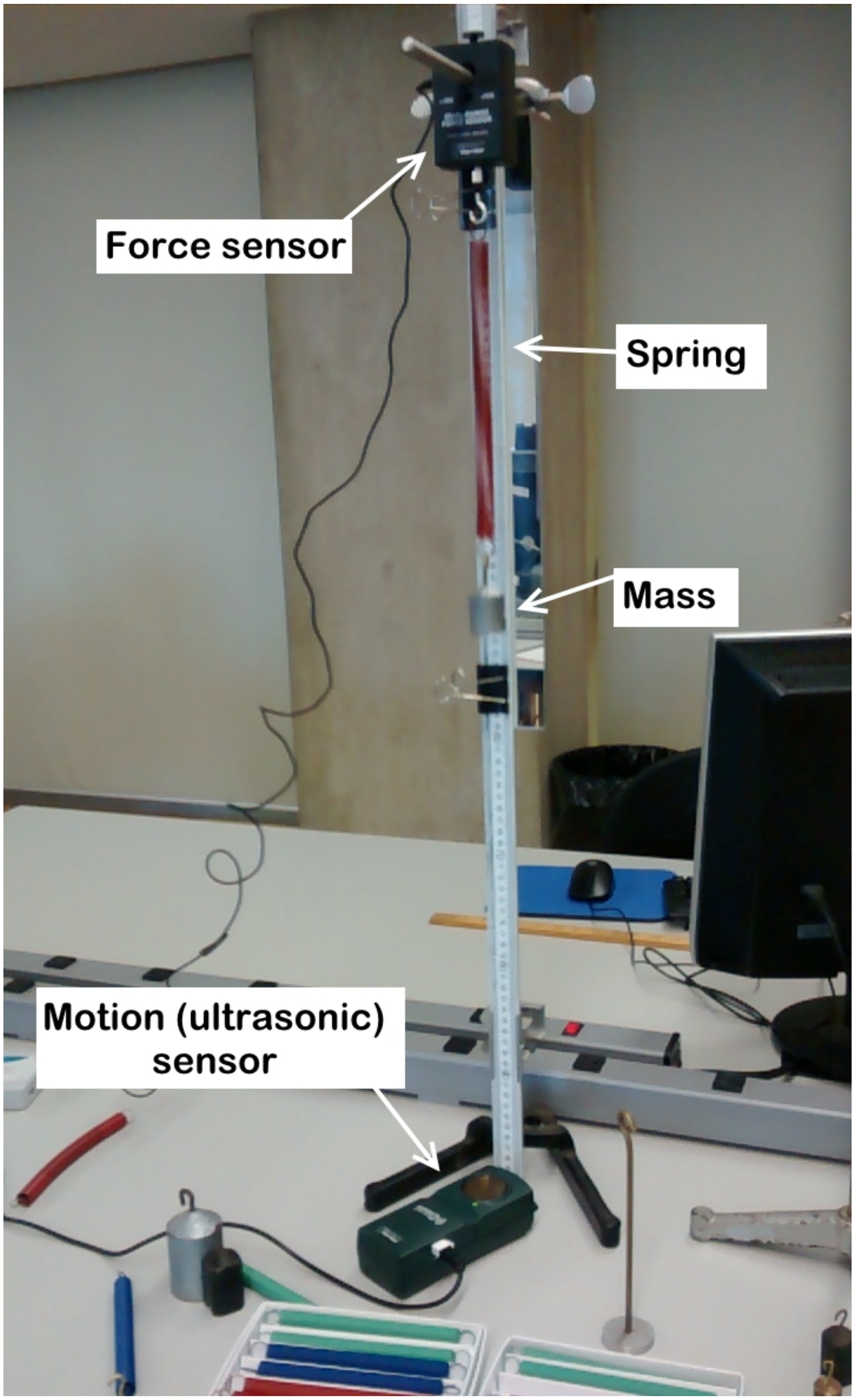

Figure 2: Setup for Experiment 2. The spring is suspended vertically and extended due to the weight of a mass attached to the end. This resting position is the equilibrium position, and the mass will oscillate about this point during simple harmonic motion.

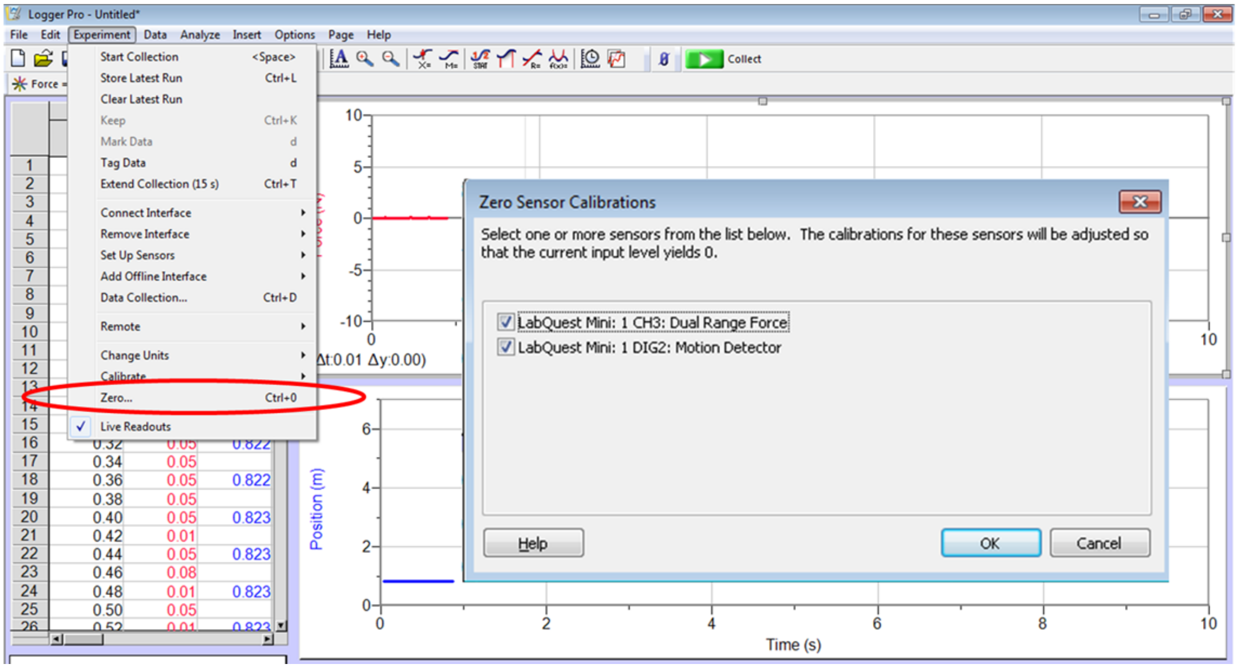

Figure 3: After the chosen mass is hung on the spring and the system comes to an equilibrium position, zero the force and the position sensors, as shown above.

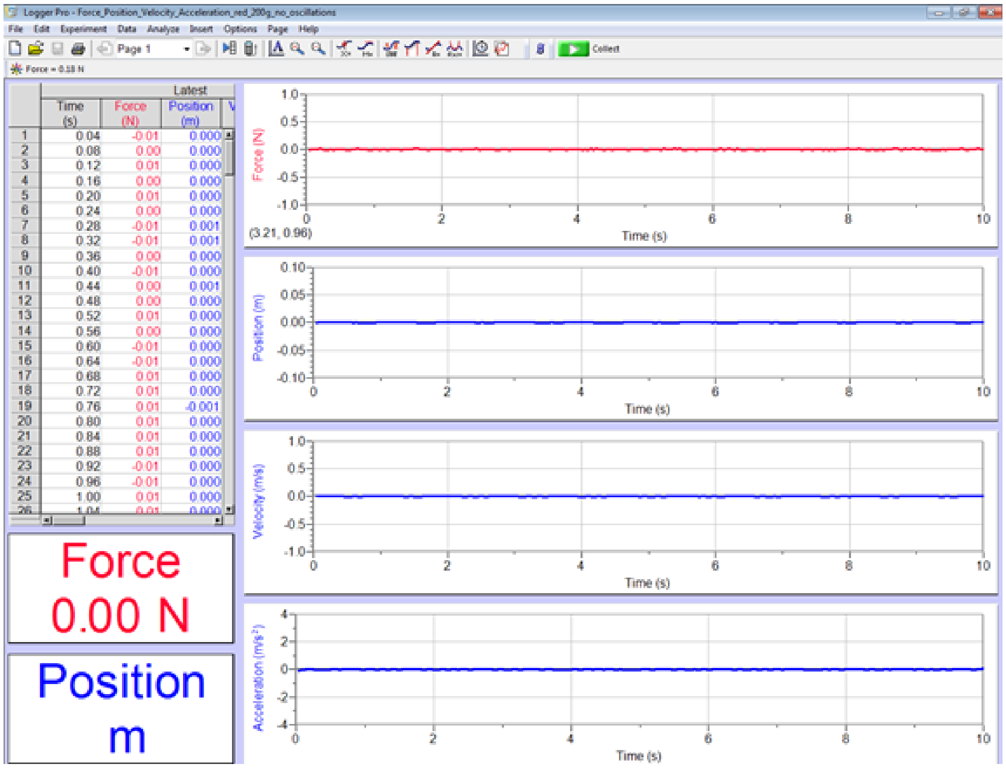

Figure 4: While the system is still at equilibrium, the baseline data can be acquired to ensure that all values at equilibrium are indeed zeroed.

EXPERIMENT 2(c): MEASUREMENTS

Once you are satisfied with having the sensors zeroed with the mass hung on the spring (at the equilibrium position), you may start the oscillation by stretching the spring to an amplitude you have chosen.

1. Choose an amplitude and record it below (do not allow the spring to stretch beyond its breaking point of 20 cm).

2. Set the mass to oscillate vertically. Wait and observe that it is oscillating vertically, then click on the green button to collect data. If you wished to start over, let the system finish collecting the data before attempting to restart. If you are happy with the oscillation, for example as shown in Figure 5, then save the data. Go into the File menu, and save the data as *.cmbl files.

3. Choose a meaningful file name, and record that into your lab manual.

4. Repeat the above with a different amplitude and save your results.

Amplitude 1 = .03 m $\pm$ .001

Amplitude 2 = .044 m $\pm$ .001

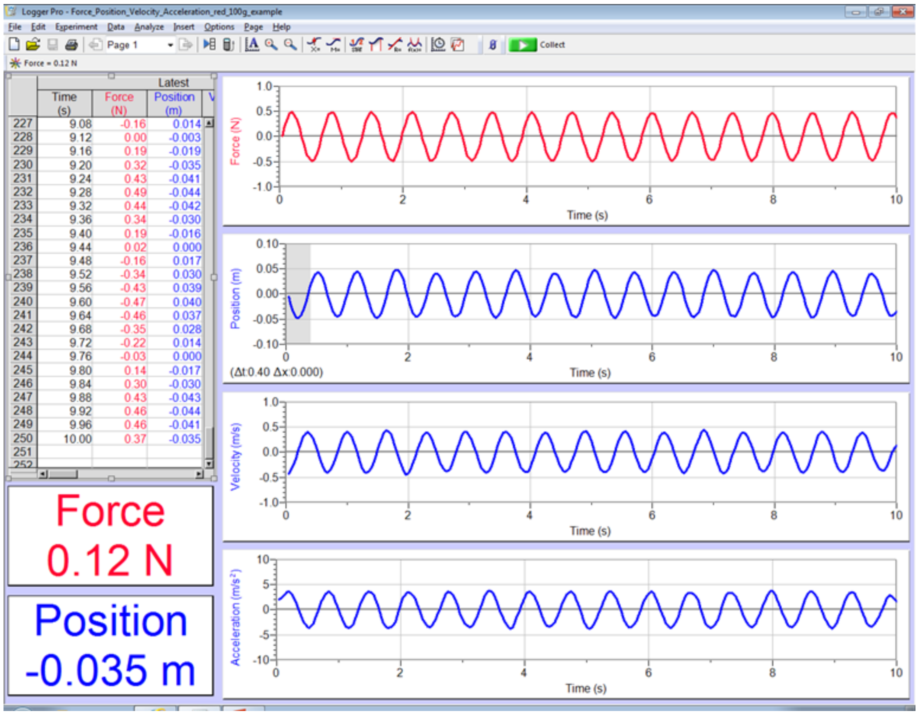

Figure 5: An example of force, position, velocity and acceleration data recorded by the force and motion sensors. Change the vertical axes to a range suitable for the oscillations in your experiment.

OBSERVATIONS

1. Starting with the Position vs. Time graph, identify times when the velocity should be a) zero and b) a maximum, and confirm that on the Velocity vs. Time graph.

   The velocity should be 0 at the max and min distances (peaks and valleys). It should be at its maximum when the displacement equals 0

2. Starting with the Velocity vs Time graph, identify times when the acceleration should be a) zero and b) a maximum, and confirm that on the Acceleration vs. Time graph.

   the acceleration should be zero at the maximum and minimum points of the velocity time graph. It should be at its maximum when the velocity is equal to zero

3. Are the oscillations in the Force vs. Time graph consistent with the Position, Velocity and Acceleration vs. Time graphs? Explain why.

   The Oscillations in the force vs time graph are consistent and in sync with those of the acceleration graph. This is because applying a force and getting and acceleration are directly linked by F = ma. The oscillations of the other graphs are consistent the the force graph they are just offset.

DATA ANALYSES

Export measured data from *Logger Pro* for data analyses in *Excel*

Under File menu in *Logger Pro*, go to export, and export using comma separated values (*.csv) format. Open the exported CSV file in *Excel*. **Note:** make sure you now save this file as an *Excel* file format (*.xlsx), otherwise, your plots will not be saved.

ANALYSIS 1: Determine parameters from *Excel* plots

Analysis 1(a): Plot Force (F) versus Position (x)

Hooke's law, $F = -kx$, tells us that the restoring force exerted by the spring to bring the mass back to the equilibrium position is proportional to how far the spring has been stretched from its equilibrium position.

1. Using the data acquired during Experiment 2, plot *Force versus Position* in *Excel*.

2. Determine the spring constant (k) from the slope.

   k = 10.215 N/m

3. Compare with the spring constant obtained in Experiment 1, and compute the percent difference. Are the two values within 10%?

   diff% = |10.215-12.117|/(.5*(10.215+12.117)) * 100
   %diff = 17 %

   The two numbers are not within 10%

Analysis 1(b): Plot Force (F) versus Acceleration (a)

Newton's second law, $F = ma$, tells us that the force exerted on a mass is proportional to its acceleration.

1. Using the data acquired during Experiment 2, plot *Force versus Acceleration* in *Excel*.

2. Determine the effective mass of the system, m_{eff}, from the slope. In addition to the mass that you hung on the spring, this effective mass also accounts for the mass of the spring itself.

   From the graph we receive a slope of .2315 kg which represents F/a which is equal to the mass. So the total mass is .2241 kg or 224.1 g.

Analysis 1(c): Plot Acceleration (a) versus Position (x)

1. Using the data acquired in Experiment 2, plot *Acceleration (a) versus Position (x)*.

2. What physical quantity does the slope represent?

   The slope represents negative angular frequency squared

3. Determine the slope.

   Slope = -44.367 rad^2/s^2

4. Determine the measured angular frequency, ω.

   Slope = -w^2 = -44.367 rad^2/s^2
   w = 6.66 rad/s

ANALYSIS 2: Kinematics equation of motion: amplitude, angular frequency, and phase of the oscillation

Using the data collected in Experiment 2, write the displacement of the oscillation as a function of time by doing the following analysis:

a) Determine the amplitude, A, of oscillation from the position data using an averaged peak value. Estimate the uncertainty, and explain the basis for your value (i.e., how you came up with that value).

A = (Amax + Amin)/2 = (.0494 + .043)/2 = .0462 m +- .004 m

In order to estimate the value I found an uncertainty that held both the maximum and minimum amplitudes within its range. I then rounded up to one significant figure as if the experiment had continued it could have produced a larger amplitude.

b) Determine the period of oscillation, T, from the measured angular frequency found in Analysis 1(c).

T = 2pi/w
T = 2pi/6.66
T = .943 s

c) Determine the phase angle, ϕ, from your acquired displacement data (using the displacement at time $t = 0$)

x = Asin(wt + p)
sin^-1(x/A) = p
p = sin^-1(-.03327/.0462)
p = -46.1

d) Write the displacement as a function of time, Equation (1), in terms of parameters A, T and ϕ.

x(t) = Asin(2pi/T * t + p)
x(t) = .0462sin(6.66t - 46.1)

ANALYSIS 3: Relationships involving the angular frequency ω in simple harmonic motion

For these steps, use percent difference tests to compare quantities.

a) Compare the angular frequency (ω) that you determined in Analysis 1 with $\sqrt{\frac{k}{m_{eff}}}$, where k is the spring constant and m_{eff} is the effective mass as measured and determined in Analysis 1(a) and 1(b), respectively.

w = 6.66

= sqrt(k/m)
= sqrt(10.215/.2241)
= 6.75

%diff = |6.66-6.64|/(.5*(6.66+6.64)) * 100
%diff = 1.35 %

The two numbers can be considered to be the same so w = sqrt(k/m)

b) Plot *Acceleration (a) versus Position (x)* in *Excel* for the second data set acquired with a different amplitude and determine the angular frequency. Compare the angular frequencies of the oscillations from two different amplitudes.

slope = -w^2 = -43.785
w = 6.62

w = 6.66

%diff = |6.66-6.62|/(.5*(6.66+6.62)) * 100
%diff = .6%

so the angular frequency is the same for each amplitude which makes sense because from the above question we know that w = sqrt(k/m) and those values remained constant across both experiments

c) From the acquired Velocity vs. Time data, determine an averaged value of the maximum velocity, v_{max}, for the oscillation. Compare this with the theoretical value, as expressed in Equation (2), using the values of A and ω determined in Analysis 1 and 2.

vmax = Aw
vmax = .0462 * 6.66
vmax = .3077 m/s

vmax = (.327+.307+.316+.309+.28+.282+.273+.283+.299+.301+.343)/11
vmax = .3018 m/s

%diff = |.3077-.3018|/(.5*(.3018+.3077)) * 100
%diff = 1.93 %

Therefore the two numbers can be considered the same which verifies vmax = Aw

ANALYSIS 4: [Optional] Kinetic and potential energies

1. Calculate the kinetic and potential energies in the *Excel* spreadsheet for one set of data collected.

2. Plot both kinetic and potential energy versus position (x) on the same graph.

3. Calculate the total energy, and add that to the graph above.

DISCUSSION AND CONCLUSIONS

1. You are given a mass and a spring, setup either in a vertical configuration, as in this lab, or horizontally. When we set the mass in motion about its equilibrium position, can it oscillate with more than one frequency? Explain.

   No it is not possible for a mass undergoing simple harmonic motion to have more than one frequency. Simple Harmonic motion is given by Asin(wt + p) or Asin((2pif)t + p). Looking at this equation we know that for simple harmonic motion w and therefore frequency must be constant meaning that there can an object undergoing simple harmonic motion may not have more than one frequency.

2. The frequency of a simple harmonic motion does not depend on its oscillation amplitude. What must then be changing to allow for the larger amplitude of oscillation within the same period?

   Given that the amplitude in simple harmonic motion is constant we are able to change the amplitude by simply starting the mass at a higher or lower position so that it oscillates more. And because period is not dependent on amplitude this will not affect the period.

Marks Table

Total Mark (Lab report + Pre-lab)	